Summary Report on the NATO/CCMS Pilot Study on Research, Development and Evaluation of Remedial Action Technologies for Contaminated Soil and Groundwater. Technical Status May 1996.

1.0 INTRODUCTION

1 This report is a review of the technology and technical themes presented to the NATO/CCMS[1] Pilot Study at the 1993, 1994, and 1996 meetings. A review of policy papers from the Pilot Study meetings is published in a companion document [11]. This report has been prepared by the Centre for Research into the Built Environment, Nottingham Trent University (CRBE) for the UK Department of the Environment, Contaminated Land and Liabilities Division (CLL) under contract EPG 1/6/21.

2 This report is based on:

(a) Written material prepared by each speaker for presentation at each of the Pilot Study meetings;

(b) Supplementary information from the published literature where appropriate and available;

(c) Summary abstracts produced by the Office of Solid Waste and Emergency Response, US Environmental Protection Agency (USEPA), Environmental Management Support Inc, and CRBE [1]; and

(d) Compiled information provided by Mr Michael Smith of MA Smith Associates acting as the NATO Fellow responsible for co-ordinating the production of the Final Pilot Study report [2].

1.1 Background

3 The United Kingdom is a member of the NATO/CCMS Pilot Study on "Research, Development, and Evaluation of Remedial Action Technologies Phase II", which is the third in a series of Pilot Studies on contaminated land treatment [3,4,5]. The Pilot Study has three main goals:

i) Evaluation and documentation of recent contaminated soil and/or groundwater treatment projects at demonstration or full-scale;

ii) Examination of emerging technologies that are at bench- or pilot-scale; and

iii) Development of a uniform data reporting system for the use of treatment technologies to encourage good practice in the presentation of results.

[1]Committee for Challenges to Modern Society (see paragraph 4)

4 This Pilot Study is one of a number conducted by the Committee for Challenges to Modern Society (CCMS) which is a part of the NATO alliance civil structure. The CCMS was initiated in 1969 by President Nixon of the USA.

5 The Pilot Study is the principal operating mechanism of the CCMS. Studies may be proposed by member countries at twice yearly plenary sessions chaired by the Secretary General of NATO. Each country may nominate a particular topic for a Pilot Study which is then accepted or declined by majority voting of the Committee members. Once approved a Pilot Study may last for up to five years before reporting its conclusions to the CCMS. It is usual for two types of final report to be published:

- A Full Report published by countries of an individual Study, for example the United States Environmental Protection Agency published the Final Report for the Pilot Study entitled Demonstration of Remedial Action Technologies for Contaminated Land and Groundwater Phase I (1986-1991) [6].

- A Summary Report of the Pilot Study's conclusions and recommendations presented in a non-technical format. This report is passed on to the CCMS and from there to the full NATO Council.

6 The proposing country of a Pilot Study nominates the Study Director who is responsible for overall co-ordination of the work. In some cases a Pilot Study also has co-proposing countries in which case the Study will also have Co-directors. There is a limited NATO programme budget for CCMS activities and therefore it is usual for participating countries to meet their own delegate costs.

7 In the UK, participation of the CCMS is overseen by the Department of the Environment (DoE) and the Ministry of Defence (MoD) in their capacities as UK CCMS Co-ordinators. They represent the UK at meetings of the full NATO/CCMS and authorise UK applications for CCMS activities. However, input to individual Pilot Studies is made by individual Divisions or Branches within Government Departments which have a specific interest in a particular Study. In this Pilot Study the UK contact is the Contaminated Land and Liabilities Branch of the DoE.

8 The current Pilot Study on contaminated land treatment follows on from the successful completion of Phase I which ran from 1987 to 1991 [4,6]. It was proposed by the USA with the support of Germany and the Netherlands who provide the current Study Director and Co-directors respectively and runs from 1992 to 1997. The Phase II Study continues to address field-demonstrated technologies while expanding the original scope from Phase I to include newly emerging approaches.

9 The intention of both Phases I and II is to act as a focus for sharing information about innovative approaches to the treatment of contaminated soil and groundwater from a range of countries, and identifying useful ways forward in developing contaminated site treatment capabilities. Their findings are expected to be used by NATO countries for assessing technologies and as reference information for technical policy development. Information exchanged includes both practical experience of full-scale applications of new technologies, descriptions of emerging technologies and fundamental under-pinning studies of established approaches for example the modelling of soil vapour extraction processes [3] and the use of soil washing in process integration [7,8,9,10].

10 The structure adopted by this Pilot Study involves countries either as "participants" or as "observers" with each country nominating a Country Representative to attend Pilot Study meetings[2]. The main work of the Pilot Study is carried out during an annual international meeting which is attended by:

- Country Representatives;
- Technical experts representing Pilot Study projects;
- Leading international experts invited to speak on topics of interest to the Pilot Study;
- Nominated guests of the host country; and
- Pilot Study Fellows (see Section 4.0).

11 Projects of potential interest to the Pilot Study are nominated by the Country Representative. Some countries have selection criteria for choosing which projects to put forward to the Pilot Study. The DoE uses criteria based on the objectives of the Pilot Study with the aim of widening coverage of Study projects and the Study's consequent review of the state of the art. The views of UK Fellows and workers on UK technical projects already accepted by the Pilot Study are sought as far as possible in the decision making process.

12 The Pilot Study decides whether or not to accept a project based on voting by all Country Representatives. The Pilot Study strives to maintain a balance between long term and short term projects[3] across a range of technology types. Projects which are accepted are expected to produce a final project report within the Pilot Study's lifetime[4] and often interim reports. Throughout the Study project presentations are open to technical scrutiny and critical review. These discussions are used in conjunction with each project's interim and final presentations as the basis for information compiled in the overall Final Report.

13 The Pilot Study is at the forefront of technology development and application. Hence, projects that might be regarded in some countries as state of the art or innovative such as applications of thermal treatment may not be accepted into this phase of the Pilot Study if they were considered in Phase I. Where an "established" technology is accepted for this study it is generally because the project focuses on a novel application or involves a fundamental investigation which offers potentially significant improvements in process optimisation.

[2] Participants are countries which have a technical project accepted within the Pilot Study while observers do not.

[3] Long term projects include technologies which are being developed in the laboratory and might not be available commercially for another 5 to 10 years. Short term projects include technologies being evaluated in full field scale trials and are therefore near-market applications.

[4] Phase II of this Pilot Study ends in 1997.

14 So far there has been four annual meetings of the Phase II Pilot Study which are shown in Table 1. In addition there was a management meeting in Nottingham, UK, in May 1995 which was attended only by Country Representatives.

Table 1: Meetings of the NATO/CCMS Phase II Pilot Study
Budapest, Hungary from October 19th to 22nd, 1992
Québec City, Canada from September 13th to 17th, 1993
Oxford, United Kingdom from September 11th to 16th, 1994
Adelaide, Australia from February 11th to 16th, 1996

15 As first envisaged, participation of NATO Pilot Studies was restricted to member countries, however, with the organisation's changing political role this has been gradually relaxed. Therefore to date, 22 nations have now participated in Phase II of the current Pilot Study including: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, France, Germany, Hungary, Italy, The Netherlands, New Zealand, Norway, Portugal, Romania, Slovak Republic, Slovenia, Sweden, Switzerland, Turkey, United States, and the United Kingdom. In addition, at the recent international meeting held in Adelaide the Pilot Study invited delegates from Asian-Pacific countries including Hong Kong, India, Indonesia, Japan, Malaysia, Pakistan, People's Republic of China, and the Republic of Korea[5]. The current status of each country attending this Pilot Study is outlined in Table 2. The projects accepted at the international meetings between 1992 and 1996, and at a management meeting in Nottingham during 1995 are also included in this table.

1.2 Report Organisation

16 This report provides a detailed summary of the technical project presentations made at the four Pilot Study meetings (see Table 1) where sufficient written information was provided to delegates. In addition, it includes summaries of the presentations made by NATO Fellows and Guest/Expert Speakers from the Québec City, Oxford, and Adelaide meetings. Further information on the Budapest meeting can be found in an earlier publication [3].

17 This report reviews the technical papers presented at the annual Pilot Study meetings with particular emphasis on the Oxford and Adelaide conferences. It is comprised of a general summary report and abstracts of the individual papers (in Annexes A to D).

[5] However only Hong Kong attended the meeting while Pakistan submitted a paper.

Table 2: Status of Countries at the 1992, 1993, 1994, and 1996 Pilot Study Meetings.

Australia	Participant. Four on-going projects, none completed.
Austria†	Participant. Attended 1992, 1993, 1994, and 1996 Meetings.
Belgium	Observer. Attended 1996 Meeting.
Canada	Participant. Two on-going projects, three completed.
Czech Republic	Participant. One on-going project.
Denmark	Participant. Two on-going projects, one completed.
France	Participant. Two on-going projects, two completed.
Germany	Co-Director and Participant. Four on-going projects, one completed.
Hong Kong	Observer. Attended 1996 Meeting.
Hungary	Participant. One completed project.
Italy†	Participant. One on-going project.
The Netherlands	Co-Director and Participant. Three on-going projects, one completed.
New Zealand	Observer. Attended 1994 and 1996 Meetings.
Norway	Participant. Three on-going projects.
Pakistan	Submitted a paper to, but did not attend, the 1996 Meeting.
Portugal‡	Observer. Attended 1993, 1994, and 1996 Meetings.
Romania	Observer. Attended 1993 Meeting.
Slovak Republic	Observer. Attended 1992 Meeting.
Slovenia	Observer. Attended 1994 and 1996 Meetings.
Sweden	Participant. One on-going project.
Switzerland	Participant. One on-going project.
Turkey	Participant. One on-going project.
United Kingdom	Participant. One on-going project, six completed.
United States*	Director and Participant. Four on-going projects, six completed.

†Austria and Italy had projects accepted at the 1992 Meeting which were subsequently withdrawn at the 1994 Meeting.
‡Portugal has two NATO Fellows but no technical projects.
*There are eleven US projects accepted by the study with the status of one uncertain.

18 Individual technical abstracts are annexed into four sections as follows:

A Technical Project Abstracts. Abstracted information on each technical project accepted into the Phase II Pilot Study since its initiation has been included. The abstracts are ordered according to an alphabetical listing by sponsoring country. Each abstract is a synopsis of the authors written and oral reporting and is not a critical review of the material presented.

Each abstract includes the current project title[6], a technical contact for further information, and an indication of project status. A Pilot Study project is described in each abstract as having given an Accepted, Interim, or Final presentation at a specific annual meeting. Accepted means that a proposal was presented to the Pilot Study and accepted by majority voting amongst Country Representatives. Interim and Final means that on-going and conclusive results of the project were respectively presented. Three projects are indicated as Withdrawn meaning that the project was removed from the Pilot Study due to problems with achieving a Final Report within the Study's reporting period 1992-97.

B Guest and Expert Presentations. Abstracted information is provided on each topic presented by invited technical experts at the Québec City, Oxford, and Adelaide meetings. Abstracts are ordered alphabetically according to speaker's surname.

C Discussion Summaries. Abstracted information is provided for lead presentation for each Pilot Study discussion at the Québec City, Oxford, and Adelaide meetings. Abstracts are ordered alphabetically according to the lead presenter's surname.

D Fellowship Presentations. A summary of the Fellowship projects accepted into the Phase II Pilot Study since its initiation has been included. Abstracts are ordered alphabetically according to sponsoring country and the Fellow's surname.

19 In addition Annex E provides a summary listing of the written papers presented at each international meeting for the technical projects. These papers were used in the preparation of each project abstract and are not widely available outside the Pilot Study. Therefore in addition to these papers a further listing of published references is included where available.

20 Annex F provides a glossary of terms used in this report.

21 Annex G provides a contacts listing of project representatives, technical experts, discussion leaders, and NATO Fellows.

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[6] The titles of several Pilot Study projects has evolved over several annual meetings. The title used for each abstract is the latest title reported at either Québec City, Oxford or Adelaide.

2.0 REVIEW OF TECHNICAL PROJECTS IN THE PILOT STUDY

2.1 Analysis of Technical Projects

22 54 technical projects have been accepted into the Pilot Study at the four annual meetings in Budapest, Québec City, Oxford, and Adelaide, and at the management meeting in Nottingham. Of these projects, three have been subsequently withdrawn and will not be included in the statistics reported in this section although their abstracts are included in Annex A. Each country is limited to a maximum of four currently active projects within the Pilot Study at any one time although during the course of the Study a country may replace completed projects with new ones. Germany, USA and the UK have all had more than four projects accepted over the lifetime of this Study. Tables 3, 4, and 5 present a complete listing of technical projects ordered alphabetically according to sponsoring country. The tables also summarise the status of the project within the Pilot Study and the technologies being investigated. Abstracts for all these projects can be found in Annex A.

23 For the purposes of this report the technologies described in each technical project have been broadly classified as one of five types: **biological**, **chemical**, **physical**, **solidification/stabilisation**, and **thermal** (see Annex F). The additional categories of **integrated** and **mixed** are used to describe combinations of technologies which are used as part of an overall remediation strategy. **Integrated** refers to approaches involving process integration where two or more technologies are used simultaneously or in series to treat a specific site problem. The use of process integration in Pilot Study projects is discussed further in Section 2.2. **Mixed** projects involve two or more technologies used in co-ordination to treat different contaminated areas or media across a site as part of an overall remedial strategy. For example the Derwenthaugh Cokeworks, near Gateshead, UK (see Annex A, page A43 and below, para 25).

24 Figure 1 shows the breakdown of technologies according to technology type. The majority of projects involve the integration of treatment technologies or the use of several processes to remediate a specific site. Individual treatment technologies often have a limited range of applicability according to contaminant type and site conditions. The combination of treatments either to address a specific mixture of contaminants or as part of an overall management strategy allows remedial technologies to address the complex contamination histories associated with many sites.

25 Such an approach was adopted for remediation of the Derwenthaugh Cokeworks, near Gateshead, UK. Covering an area of 7.9 ha the site was contaminated with a range of waste products from the coal carbonisation process including BTEX, PAHs, phenols, heavy metals and cyanides with significant concentrations of contaminants found in both the soil and groundwater. The remedial strategy adopted involved the use of four technologies in co-ordination: containment, *in situ* soil vapour extraction (SVE), *ex situ* pump and treat, and *ex situ* landfarming.

Table 3: Listing of Pilot Study technical projects according to sponsoring country (Australia to Germany) showing their status, technology type, and abstract location in Annex A.

Sponsoring Country	Project Title	Status /Type	Annex Page
Australia	Trial of Air Sparging of a Petroleum (Gasoline) Contaminated Aquifer	I,P	A2
	Bioremediation of Phenol Contaminated Soils on Coode Island	I,B	A3
	Bioclogging of Aquifers for Containment and Remediation of Organic Contaminants	I,B	A4
	Remediation of Methyl Ethyl Ketone Contaminated Soil and Groundwater	I,P	A5
Austria	Technical and Economic Aspects of *In Situ* Bioremediation	W,B	A6
Canada	*In Situ*/ On Site Bioremediation of Industrial Soils Contaminated with Organic Pollutants: Elimination of Soil Toxicity with *Daramend*™	F,B	A7
	Biopile Technology for the Treatment of Organic Contamination in Soil	F,B	A8
	Integrated Treatment Technology for the Recovery of Inorganic and Organic Contaminants from Soil	I,In	A9
	Demonstration of Thermal Gas-Phase Reduction Process	F,T	A10
	Field Demonstration of an *In Situ* Treatment for Hydrocarbon Contaminated Sites Using Well Points	A,In	A11
Czech Republic	Soběslav, South Bohemia Wood Treatment Plant	A,Mx	A12
Denmark	Biodegradation of PAHs at Frederiksberg Gasworks	I,B	A13
	Groundwater/Soil Remediation at a Former Manganese Sulphate Plant	I,Mx	A14
	Rehabilitation of a Site Contaminated by Tar Substances Using a New On-Site Technique	F,T	A15
France	Ozone Treatment of Contaminated Groundwater	F,In	A16
	Soils of Garbage Dumps of Coal Tar and Petroleum Tar Distillation Plants	A,B	A17
	Innovative *In Situ* Groundwater Treatment System	I,P	A18
	Treatment of Polluted Soil in a Mobile Solvent Extraction Unit	I,C	A19
Germany	Assessment of a Biological *In Situ* Remediation	F,B	A20
	Cleaning of Mercury-Contaminated Soil Using a Combined Washing and Distillation Process	I,In	A21
	Mobile Low Temperature Thermal Treatment Process	I,T	A22
	Permeable Treatment Beds	A,Mx	A23
	Fluidised Bed Soil Treatment Process - *BORAN*	A,T	A25

Status: A (Accepted), I(Interim), F (Final), W (Withdrawn).
Type: B (Biological), C (Chemical), P (Physical),T (Thermal), S (Solidification/Stabilisation), In (Integrated), Mx (Mixed).

Table 4: Listing of Pilot Study technical projects according to sponsoring country (Hungary to United Kingdom) showing its status, technology type, and abstract location in Annex A.

Sponsoring Country	Project Title	Status /Type	Annex Page
Hungary	Environmental Problems at Tököl Airbase and Other Former Soviet Military Bases in Hungary	F,Mx	A26
Italy	Application and Development of Ground Penetrating Radar System for the Determination of Pollutants in Contaminated Areas	W,Mx	A27
	Forced Soil Washing Using UV and Hydrogen Peroxide	W,C	A28
	Biological Treatment of Soil Contaminated with Aromatic Hydrocarbons	A,B	A29
The Netherlands	Combined Remediation Technique *FORTEC*™	F,In	A30
	Slurry Decontamination Process	I,B	A31
	Modelling and Optimisation of *In Situ* Remediation	I,Mx	A32
	In Situ Bioremediation of Chloroethene Contaminated Soil	A,B	A33
Norway	Treatment of Creosote Contaminated Soil	I,In	A34
	Use of White Rot Fungi for Bioremediation of Creosote Contaminated Soil	I,B	A35
	Soil Washing and DCR Dehalogenation of PCB Contaminated Soil	I,In	A36
Sweden	Treatment of PAH and PCP Contaminated Soil in Slurry-Phase Bioreactors	A,B	A37
Switzerland	Re-use of Bioremediated Soils/Long Term Degradation of Hydrocarbon Residuals	A,B	A38
Turkey	Sorption/Solidification of Selected Heavy Metals and Radionuclides from Water	I,S	A39
UK	*CACITOX*™ Soil Treatment Process	F,In	A40
	In-Pulp Decontamination of Soils, Sludges and Sediments	F,In	A41
	Using Separation Processes from the Mineral Processing Industry for Soil Treatment	F,P	A42
	In Situ Soil Vapour Extraction within Containment Cells Combined with *Ex Situ* Bioremediation and Groundwater Treatment	F,Mx	A43
	Enhancement Techniques for *Ex Situ* Separation Processes Particularly with Regard to Fine Particles	F,In	A44
	Chemical Fixation of Soils Contaminated with Organic Chemicals	I,S	A45
	Decontamination of Metalliferous Mine Spoil	F,In	A46

Status: A (Accepted), I(Interim), F (Final), W (Withdrawn).
Type: B (Biological), C (Chemical), P (Physical),T (Thermal), S (Solidification/Stabilisation), In (Integrated), Mx (Mixed).

Table 5: Listing of Pilot Study technical projects from the United States showing their status, technology type, and abstract location in Annex A.

Project Title	Status /Type	Annex Page
In Situ Microbial Filters	F, B	A47
In Situ Treatment of Chlorinated Solvents	F,C	A48
Bioventing in the Subarctic Environment	F,In	A49
Enhanced *In Situ* Removal of Coal Tar: Brodhead Creek Superfund Site	F,P	A50
Basket Creek Surface Impoundment	F,In	A51
Multi-Vendor Bioremediation Technology Demonstration Project	I, B	A52
Integrated Pneumatic Fracturing/Bioremediation for the *In Situ* Treatment of Contaminated Soil	A,In	A53
Demonstration of Peroxidation Systems Inc *Perox Pure*™	F, C	A54
Integrated Rotary Steam Stripping and Enhanced Bioremediation for *In Situ* Treatment of VOC Contaminated Soil	I,Mx	A55
Czechowice Oil Refinery Project	A,Mx	A56

Status: A (Accepted), I(Interim), F (Final), W (Withdrawn).
Type: B (Biological), C (Chemical), P (Physical),T (Thermal), S (Solidification/Stabilisation), In (Integrated), Mx (Mixed).

26 SVE was used to remove volatile contaminants and free phase contamination from the soil and groundwater prior to pump and treat operations and soil excavation. The pump and treat system removed the remaining non-volatile components of the groundwater including cyanides and sulphides. Land farming treated the remaining non-volatile and recalcitrant organic contamination remaining in the mose severely contaminated soils after SVE had removed the volatile components. By combining several approaches a complete risk management scheme was implemented.

27 The Pilot Study accepts technical projects in two areas of development: **emerging** and **demonstration**. For the purposes of this report an emerging technology has been evaluated at bench- and pilot-scale whilst a demonstrated technology has been implemented at field- or full-scale. Demonstrated technologies are usually much nearer to commercial application. There is almost a fifty-fifty split of projects within the Pilot Study examining emerging and demonstrated technologies.

28 Figure 2 shows the breakdown of technical projects according to contaminant types treated. The majority of projects are concerned with the treatment of organic contaminants including PAHs, PCBs, and BTEX compounds. Dealing with metal contaminants such as mercury, cadmium, and arsenic is considered by a disproportionately small number of projects. It is interesting to note that the majority of projects dealing with metal contamination have been sponsored by the UK. This maybe a reflection of the UK's considerable history of metalliferous mining and the quality of our technical expertise in mineral engineering. In addition to those projects studying metal inorganics, one project focuses on remediation of inorganic sulphates and cyanides at

a former works in the town of Marktredwitz, Germany (see Annex A, page A21). An increasing number of projects are also addressing the problems of mixed organic and metal contamination which is a common problem at many sites.

2.2 General Technology Themes for Pilot Study Projects

2.2.1 Process Integration

29 Process integration is a method of overcoming practical limitations of technology performance and to broaden their range of applications in both site conditions and contaminant type. Process integration can involve the combination of several treatment technologies in series[7] or simultaneously.

30 The use of treatment technologies in series is a theme of several Pilot Study projects (see Table 6). For the purposes of this report in series process integration involves the treatment of residual projects from one treatment by a subsequent treatment. In the UK and internationally considerable research has been conducted into the use of *ex situ* physical soil separation (also known as soil washing) as an enabling technology for further treatment [12].

31 Soil washing can be used as a pretreatment step to reduce the volume of material requiring further treatment or disposal by removal of relatively clean soil fractions from highly contaminated concentrates. In many cases this is considered to be the removal of coarse grained sands and gravels from the silt and clay soil fraction. A further advantage of soil washing is that the separated soil fractions can be tailored (in terms of physical properties such as grain size and density) to meet the optimised feed characteristics of the subsequent treatment process. Within the Pilot Study, soil washing has been combined with slurry-phase bioremediation, thermal desorption, fluidised bed incineration, and solvent extraction.

32 The use of mineral processing techniques to enhance the soil washing of fine grained contaminated soils[8] was investigated as a part of a UK project (see Annex A, page A44). A review of commercial washing plants had highlighted that fines were often separated for disposal from coarser fractions as a treatment process [13]. This practice would be uneconomical for many UK sites since the amount of fines in UK soils often exceeds 30-35%. The study examined a number of techniques for improving the disaggregation, separation, and dewatering of fines particles and concluded that treatment of soil fractions down to a particle size of 0.002 mm was possible. This significantly increased the potential economic applicability of soil washing to UK conditions and soils with a high silt and clay content in general. The combination of enhanced fines separation with slurry-phase bioremediation was examined for two soils contaminated with diesel and PAHs respectively.

[7] In the US this type of process integration is known as a "treatment train"

[8] For this project the term fine grained was applied to particles of garin sizes less than 0.063 mm which may be approximated to the silt and clay fractions

Table 6: Examples of Pilot Study projects which involve the integration of technologies in series to form a treatment train

Integrated Treatment Technology for the Recovery of Inorganic and Organic Contaminants from Soil (Annex A, A9)	soil washing, solvent extraction
Rehabilitation of a Site Contaminated by Tar Substances Using a New On-Site Technique (Annex A, A15)	soil washing, thermal desorption
Ozone Treatment of Contaminated Groundwater (Annex A, A16)	chemical oxidation, bioremediation
Fluidised Bed Soil Treatment Process - *BORAN* (Annex A, A25)	soil washing, fluidised bed incineration
Treatment of Creosol-Contaminated Soil (Annex A, A34)	soil washing, slurry-phase biotreatment
Soil Washing and DCR Dehalogenation of PCB-Contaminated Soil (Annex A, A36)	soil washing, chemical dehalogenation
Enhancement Techniques for *Ex Situ* Separation Processes Particularly with Regard to Fine Particles (Annex A, A44)	soil washing, slurry-phase biotreatment
Decontamination of Metalliferous Mine Spoil (Annex A, A46)	soil washing, solvent extraction

33 Several projects reported practical experiences of integrated technologies in full-scale operation. A Danish project (see Annex A, page A15) reported on the remediation of a former gasworks in the heart of Copenhagen using a combination of soil washing and thermal desorption. Soil washing was used to provide a volume reduction step by producing clean fractions in the particle size ranges >0.05m and 0.002-0.05m through screening and high pressure spray washing. The contaminated fines (sizes <0.002 m) were treated by thermal desorption to destroy the PAH and other coal tar contaminants present. The combination of soil washing and thermal desorption offered significant economic savings over thermal treatment of all excavated material.

34 In addition to the treatment train approach, process integration can also involve the combination of one or more processes to enhance performance through concurrent treatment. For example bioventing is the combination of soil vapour extraction (SVE) with *in situ* bioremediation [14]. It aims to address a significant problem for *in situ* biological treatment which is its ability to deliver sufficient nutrients and oxygen to the active microbial population to ensure optimised contaminant degradation. In bioventing, SVE is used to stimulate *in situ* bioremediation by supplying oxygen through inducing subsurface air flow. In many bioventing systems SVE's primary purpose of removing volatile contaminants is suppressed by reducing air flow rates since above ground treatment of waste gases is an expensive operation. Bioventing can reduce SVE treatment costs by degrading contaminants below ground. It enhances bioremediation because it can supply oxygen more efficiently than aqueous based delivery systems, both in terms of its oxygen carrying capacity and through its higher soil conductivity.

35 Other projects have built on the international state of the art in bioventing and other integrated technologies. For example projects sponsored by the USA and the

Netherlands have examined the operation of bioventing in cold climates (see Annex A, page A49), the predictive modelling of SVE and bioventing processes (see Annex A, page A32), and the use of pneumatic fracturing to enhance *in situ* treatment (see Annex A, page A53).

2.2.2 Active Containment

36 There is growing awareness of the environmental problems caused by groundwater pollution, in particular the presence of toxic organic contaminants in shallow and deep aquifers. Conventional approaches to groundwater treatment may involve a three stage process comprising groundwater extraction, above-ground water treatment, and re-injection of the treated water of treated water (commonly called "pump and treat"). Alternatively physical barriers such as slurry trench cut-off walls are commonly used to prevent migration of contaminated groundwater off-site, where treatment of the source of contamination may not be technically or economically viable [14].

37 Active containment is intended to reduce the cost and increase performance of groundwater treatment compared with conventional approaches. It may be used to reduce the risks from a contaminated site without necessarily treating the contamination at source. Active containment is a generic term which covers a wide range of systems: reactive zones, reactive walls, bio-screens, funnel and gate, and sparge walls [15,16]. There are three Pilot Study projects which are pertinent to this topic:

- *in situ* microbial filters (see Annex A, page A47);
- bioclogging of aquifers (see Annex A, page A4); and
- development of permeable treatment beds (see Annex A, page A23).

In addition, Dr James Barker at the University of Waterloo, Canada, made a presentation to the Oxford meeting of the Pilot Study on *in situ* groundwater treatment using "funnel and gate" systems (see Annex B, page B3).

38 The **bioclogging** project involves an investigation of the manipulation of poly-saccharide producing bacteria to reduce the hydraulic conductivity of aquifer sediments and thereby reduce the mobility of contaminated groundwater plumes. This "bioclogging" effect is believed to result from several different processes acting in sediment pore spaces including the production of low solubility gaseous end products, the excretion of extra-cellular polysaccharides, and the increase in bacterial cell numbers. This phenomena has often been noted during *in situ* bioremediation projects where it was considered to be an operational nuisance. An additional aim of the system is to heighten biodegradation of contaminants through an increase of biomass. The system has been evaluated at bench-scale in preparation for a field-scale trial.

39 The **permeable treatment bed** project will investigate the development of a vertical bed for use as an active containment system. Although still at the conceptual development stage the system will be based on an excavated trench into which a pre-fabricated panels of a double wall is inserted (see diagram on page A24). The reactive treatment bed matrix is emplaced within the double wall layer so that it can be removed and replaced (for example after sorption capacity is reached) without the wall collapsing.

Several treatment systems are proposed for the reactive matrix including zero valent iron filings which have been shown to dehalogenate certain chlorinated solvents by chemical reaction [17].

40 James Barker at the University of Waterloo outlined the "funnel and gate" approach to *in situ* groundwater remediation which has received considerable attention internationally. In this system low permeability vertical barriers, such as slurry trench cut-off walls are placed across the path of a contaminated groundwater plume to contain and control its movement (i.e. "the funnel"). Gaps in the impermeable barrier, containing a permeable treatment bed similar in concept to the one outlined above (i.e. "the gate"), allows passage of groundwater through the wall to be combined with its treatment. Groundwater migrating through the barrier is therefore remediated to a predetermined water quality standard down gradient. This approach is especially applicable to diffuse sources of contamination and where the source cannot be treated. It has been reported that several "funnel and gate" systems have been installed internationally including the UK [17].

3.0 GUEST AND EXPERT PRESENTATIONS TO PILOT STUDY MEETINGS

41 At each annual meeting technical experts are invited to present state-of-the-art information and opinion to the delegates in order to inform and stimulate debate within the Study forum. A complete listing of the presentations and discussions is provided in Tables 7 and 8 with reference to the summary abstracts in Annex B and C. Selected points of interest from these presentations are outlined in the following paragraphs.

Table 7: Group Discussions from the Québec City, Oxford, and Adelaide meetings. Note that an # indicates that an abstract was not possible due to insufficient written material.

Meeting	Speaker	Title (Annex C Page Reference)
Québec City	Stephen James (USA)	#Discussion of Critical Technologies for Each Country
	John Kingscott (USA)	Markets for Innovative Environmental Technologies (C4)
	Walter Kovalick (USA)	Cost performance data: collection and format (see discussion at Oxford meeting, C5)
	Ester Soczó (Netherlands)	#Emerging Technologies
Oxford	Walter Kovalick (USA)	Remediation Cost and Performance Initiative and Benefits of Public/Private Partnerships for Evaluation of Remedial Technologies (C5)
	Kelvin Potter (UK)	International Review of Industry Needs for Treatment Technology (C6)
Adelaide	Volker Franzius (Germany)	NATO/CCMS Pilot Study on Environmental Aspects of Reusing Former Military Lands (C2)
	Harald Kasamas (Austria)	CARACAS (C3)
	Rob Thomas (Australia)	The International Symposium on the Clean-Up of Manufactured Gas Plants (C7)

42 An introduction to **extensive** treatment approaches having a lower energy and other resource requirement compared to conventional treatment technologies was provided by *van Veen* (B15). Although treatment times for such approaches are reportedly much longer than more aggressive treatments this was not considered a problem from the industrial viewpoint presented by *Potter* (C6) who considered low cost to be a priority.

43 *Barker* (B3) introduced the concept of active containment and "funnel and gate" treatment for contaminated groundwater (see Section 2.2.2). *Marvan* (B11) discussed the importance of real time chemical analysis for remediation process control and site investigation. He reported on a Canadian review of real time analytical methods which had been carried out in conjunction with on-site technology developments. *Stauffer*(B14)

Table 8: Guest and expert presentations from the Québec City, Oxford, and Adelaide meetings

Meeting	Speaker	Title (Annex B Page Reference)
Québec City	Ayse Filibeli (Turkey)	Solidification of flyash samples coming from solid waste incineration plants (B5)
	Johan van Veen (Netherlands)	Decision systems for the selection of technologies for clean-up of contaminated sites (see Oxford, B15)
Oxford	Jens Andersen (Denmark)	Danish Assistance in the Remediation of Tököl Airbase (B2)
	James Barker (Canada)	Controlled *In Situ* Groundwater Treatment (B3)
	Paul Richter (USA)	Selection of Remedial Technologies (B5)
	Jan Freijer (Netherlands)	Prediction and Optimisation of the Abiotic Environment in Landforms to Enhance Biodegradation of Hydrocarbons (B6)
	Andrew Leeson (USA)	US Air Force Bioventing Initaiative (B10)
	Johan van Veen (Netherlands)	Selection of Remedial Options for Contaminated Sites (B15)
Adelaide	Patrick Davoren (Australia)	Rehabilitation of Former British Nuclear Test Sites at Maralinga, South Australia (B4)
	Jeffrey Impens (Australia)	Mile End Railyards Redevelopment Project (B7)
	Rune Jespersen (Denmark)	Electrodialytic Soil Remediation (B8)
	Andrew Langley (Australia)	The Interface Between Risk Assessment and Remediation: Choosing a Method of Risk Assessment Appropriate for Australia (B9)
	Igor Marvan (Canada)	Evaluation of Six Near-Real-Time Analytical Methods (B11)
	Mark McNamara (Australia)	Introduction to the Homebush Bay Rgeneration Project (B12)
	SRL PLASMA Ltd (Australia)	Plascon™ Hazardous Waste Destruction Process (B13)
	Thomas Stauffer (USA)	Natural Attenuation of JP4 Spill (B14)

reported on an investigation of intrinsic bioremediation of a contaminatedplume in the USA. It was suggested that this study showed conclusive evidence that intrinsic bioremediation can occur in contaminated aquifers at a rate sufficient to be an effective and low cost risk management option.

44 Several presentations at the Adelaide meeting reviewed new international fora for the the reporting and discussion of contaminated land remediation and risk assessment. These included a sister NATO/CCMS Pilot Study on investigation and remediation of military lands (C2); and CARACAS - a European initiative to provide guidance and recommendations for assessing risk of contaminated land in Europe (C3).

4.0 NATO/CCMS PILOT STUDY FELLOWSHIPS

45 NATO/CCMS Fellowships enable participation by experts in the international meetings of the Pilot Study with financial awards by the CCMS to cover travel and subsistence to each annual meeting. Each Fellow has a project or topic area of interest to the Pilot Study and several are involved directly with preparation of the Pilot Study Final report.

46 There are currently 10 Fellowships in this Pilot Study (see Table 9) of which 8 are summarised in Annex D.

Table 9: Fellowships awarded up to and including the Adelaide meeting in February 1996. An # indicates that no written summary of this Fellowship is included in Annex D.

Fellow	Topic (Annex D Page Reference)
Kai Steffens (Germany)	Concepts of Quality Management in Testing and Monitoring of Innovative Technologies for Remedial Actions on Contaminated Land and Groundwater (D2)
Hans-Joachim Steitzel (Germany)	Innovative Approaches Used on Large Remediation Projects in Germany (D3)
Maria Chambino (Portugal)	Review of the Contaminated Land Situation in Portugal (D4)
Resat Apak (Turkey)	#Untitled - in support of Turkish Technical Project (Annex A, A39)
Mike Smith (UK)	Code of Practice and Quality Management of Project Reports to Assist Compilation of the Pilot Study Final Report (D5)
Robert Bell (UK)	#Review of Quality Assurance and Control Systems Used by the Individual Projects
Mary Harris (UK)	Costs of Remediation and Implications for Technology Transfer (D6)
Domenic Grasso (USA)	Why Some Emerging Technologies Fail at Hazardous Waste Sites ? (D7)
Robert Siegrist (USA)	In Situ Remediation of Organics: Process Design, Treatment Efficiency, and Performance Assessment (D7)

Notes: A further untitled Fellowship has been awarded to Turkey. The Portuguese Fellowship is shared.

5.0 FUTURE DEVELOPMENTS

47 The final meeting of the Pilot Study Phase II will take place during Spring 1997 in the USA. The exact location has yet to be decided. A management meeting will take place in Bonn during September 1996.

48 Final Report writing is now underway. The structure agreed for the report is summarised in Table 10. Publication is anticipated as being through the United States Environmental Protection Agency during 1998. However, this has yet to be confirmed. The possibility of a final report material being made available through the Internet is also being considered.

49 The USA has proposed a Phase III Pilot Study to begin in 1998. The proposal has the informal agreement of many of the countries taking part in the current Phase II Pilot Study, although discussion about its exact coverage and organisation is still taking place. The general view is that any Phase III will need to be more structured and that the management will need to be highly pro-active in directing the projects. There is also a view that the Pilot Study needs a more specific focus of attention than purely reporting on technology developments and demonstration. One possibility is linking technology reports to more broadly based environmental impact assessments and considerations of sustainability.

Table 10:	Agreed structure for the Pilot Study Phase II Final Report.
Chapter 1:	Introduction, Overview, and Conclusions
Chapter 2:	Overview of Technologies
Chapter 3:	*In Situ* Treatment
Chapter 4:	Physico-chemical
Chapter 5:	*Ex Situ* Biotreatment
Chapter 6:	Solidification/Stabilisation
Chapter 7:	Thermal
Chapter 8:	Other
Chapter 9:	Specific Sites: Gasworks etc
Chapter 10:	Costs
Chapter 11:	Documentation/QA
Chapter 12:	Integration of Technologies
Chapter 13:	Conclusions and Recommendations

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51 The summaries contained in this report are based on papers submitted to and presentations made at the Pilot Study. Consequently, the authors of this summary report do not necessarily support the views of conclusions drawn in the projects, nor do they verify the accuracy of any data presented.

52 This report updates an earlier summary report produced by the United States Environmental Protection Agency: EPA Report. EPA/542/R-95/006 (1995) with the assistance of the authors of this work.

53 This report is based on collation work carried out under contracts EPG 1/6/7 and EPG 1/6/21 for the UK Department of the Environment.

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